# Hourly weather observations from the Scottish Highlands (1883-1904) rescued by volunteer citizen scientists

Ed Hawkins[1*], Stephen Burt[1], Philip Brohan[2],
Michael Lockwood[3], Harriett Richardson[4], Marjory Roy[5], Simon Thomas[3],
and more than 3500 volunteers

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1. NCAS-Climate, Department of Meteorology, University of Reading. 2. Met Office Hadley Centre, Exeter. 3. Department of Meteorology, University of Reading. 4. National Centre for Atmospheric Science, University of Leeds. 5. Scottish Centre, Royal Meteorological Society. *corresponding author(s): Ed Hawkins (e.hawkins@reading.ac.uk)

**Abstract**

Weather observations taken every hour during the years 1883-1904 on the summit of Ben Nevis (1345m above sea level) and in the town of Fort William in the Scottish Highlands have been transcribed from the original publications into digital form. More than 3500 citizen scientist volunteers completed the digitisation using the WeatherRescue.org website in less than three months. Over 1.5 million observations of atmospheric pressure, wet and dry bulb temperatures, precipitation and wind speed were recovered. These data have been quality controlled and are now made openly available, including hourly values of relative humidity derived from the digitised dry- and wet-bulb temperatures using modern hygrometric algorithms. These observations arguably represent the most detailed set of weather data available for anywhere in the UK in the Victorian era. In addition, 374 observations of aurorae seen by the meteorologists from the summit of Ben Nevis have been catalogued and this has improved the auroral record for studies of space weather.

## Dataset

Title: Meteorological Observations taken from Ben Nevis and Fort William (1883 -1904)
Creator: Ed Hawkins, Stephen Burt, Marjory Roy
Publisher: CEDA
Publication year: 2019
DOI: to be created when paper resubmitted after revisions
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## 1 Introduction

Between December 1883 and September 1904 a group of meteorologists undertook detailed weather observations at the summit of Ben Nevis, the highest mountain in the United Kingdom, at 1345m above sea level. For nearly 21 years the summit observatory was continuously operating, often completely isolated during the winter. Every hour during the day and night one of the meteorologists recorded detailed observations of the weather including atmospheric pressure, temperature (both wet and dry bulb), rainfall, wind strength and direction, sunshine, and cloudiness. They also made detailed notes of atmospheric phenomena such as aurorae, haloes and glories. Kilgour (1905) and Roy (2004) provide detailed accounts of life at the observatory. Some photographs taken by the observers at the summit are shown in Figure 1.

Between August 1890 and September 1904, parallel weather observations every hour were taken near sea level in a dedicated Observatory in the town of Fort William, just a few kilometres from the summit of Ben Nevis. The same hourly weather observations were recorded, except that the cloudiness and wind measurements were not taken. Between December 1883 and December 1890, observations were also taken at Fort William School several times daily. The observations were all published in the Transactions of the Royal Society of Edinburgh in four volumes (Buchan (1890); Buchan and Omond (1902, 1905, 1910)) but they have never been digitised.

These data arguably represent the most detailed set of weather observations for this period anywhere in the UK, and certainly in a mountain environment. No regular weather observations have been taken on Ben Nevis since the summit observatory closed in 1904.

The transcription (or 'rescue') of these data from paper to digital format has now been completed with the help of thousands of volunteer 'citizen scientists'. This paper describes the data rescue process, and makes the data openly available for anyone to use. This fulfils the ambitions of the meteorologists of over a century ago that their data be made available to aid weather forecasting and the study of mountain meteorology. The volunteer approach to the data rescue is particularly fitting given that the Observatories themselves were largely crowd-funded.

# 2 Citizen science approach to collecting data

## 2.1 Website development

An example page from the published volumes is shown in Figure 2, showing the temperature observations for September 1904 - the final month of measurements. In total, $\sim$2100 images like this were available from scans of the original published documents.

The Zooniverse (zooniverse.org) provides a popular way of developing citizen science projects. Using their Project Builder interface, a custom website was created to enable volunteers to transcribe the data from the images. A 'beta' version of the website was produced and reviewed by a selected group of experienced Zooniverse volunteers who provided valuable feedback on improvements to be made.

The images were split into several batches, selected by observation type and Observatory. The volunteers were required to complete four tasks on a randomly selected image from a particular batch. They were asked to confirm that the image displayed was for the expected weather type and Observatory, e.g. temperature on Ben Nevis. They were then asked to select the month and year the data was for from a set of drop-down menus, followed by a request to draw a box around a specific column of data, e.g. the wet bulb temperature at 4am. They then typed the data shown in that column, including the bottom row which represented the mean (or sum for the rainfall data). A total of around 52,000 columns were entered, each by at least three independent volunteers so that keying errors could be picked up later.

Assuming it took an average of 4 minutes to complete the tasks for a single column, this equates to over 10,000 person-hours of effort, or over 6 years on a full-time basis. The website launched in September 2017 and in less than 3 months all of the image tasks had been completed with more than 3500 volunteers completing the transcription of at least one column. Around 700 volunteers were responsible for more than 75% of the transcriptions.

## 2.2 Choices made and lessons learnt

### 2.2.1 Decisions about project design

From the start of the website design it was considered that asking volunteers to enter an entire table (like shown in Figure 2) was too much for a single task. The challenge was to break the project into smaller, more manageable pieces. For example, a decision was needed about whether to ask for specific rows or columns of data. Due to the image dimensions it was decided that it was easier for the volunteers to type in a whole column, rather than a row, to minimise the amount of required zooming and scrolling around the image. However, recent evidence from other data rescue efforts suggests that it is easier to make mistakes reading down a column than across a row (Ryan *et al.*, 2018).

A decison was also required about how many volunteers would be needed to type in each column to ensure accuracy. Obviously, the more repeats required, the slower progress would be, but the resulting data would require less manual correction of errors. We decided on 3 repeats per column. The presence of the extra tabulated rows and columns for the mean or sum also provided an extra check on the accuracy of the keying and were used to find errors. If there was disagreement amongst the volunteers then the value was flagged for manual checking. Without the extra mean rows and columns, five repeats would probably have been required, meaning the project would have taken much longer.

It was also decided that the project needed to be split into batches of images as we were uncertain about the number of volunteers that might be recruited. The last 7 years of the observatory data (1898-1904) was the first batch chosen, with the aim of completing the transcription of a short period at the very least. In fact, the project was far more popular than expected so the images for 1893-1897, 1888-1892 and finally 1883-1887 were added in turn. These were the four periods in the published volumes, ensuring consistency of table design within each batch.

Lastly a decision was required about which weather variables we wanted to rescue. Temperature, precipitation, and pressure were agreed as the highest priority, although many of the Ben Nevis wind observations were also rescued. The cloudiness and sunshine data, and the remaining wind observations, are still undigitised, but the images are available for anyone to examine, especially for particular case studies. Brönnimann *et al.* (2006) describes a process to consider when making such decisions.

#### 2.2.2 Lessons learnt

There are several factors which helped ensure the success of this project. Firstly, the story of the intrepid weathermen living in such a remote environment, struggling with the weather, is a wonderful 'hook' to get people interested in becoming involved. As a result we were able to get coverage of the project in the media, especially the BBC (Amos, 2017) and in Scottish local newspapers. Twitter was also highly useful tool for spreading information about the project. Lastly, actively engaging with the volunteers through the website forums and providing regular updates on their progress was essential and provided reassurance to the volunteers that they were doing useful science. Several volunteers commented that the Weather Rescue project team was one of the most engaged they had seen across a range of Zooniverse projects and this was helpful and encouraging to them.

### 2.3 Data processing and error checking

The data collected through the web interface was regularly sent to the project team. For each column, the entries were collected and compared. The data for each column was further separated into individual table cells. Where at least two of the typed entries agreed, the value was provisionally accepted. If there was complete disagreement then the cell was flagged for manual checking. The data for each variable and each month were output as individual spreadsheets, representing the digital equivalent of each page (Figure 2). The spreadsheets included an extra row and column for the calculated mean (or sum for rainfall) which was compared with the typed mean (or sum). Where these disagreed, manual checks were performed to resolve disagreements.

#### 2.3.1 Sources of disagreements

Where the typed mean or sum value disagreed with the calculated value, every hourly value was checked against the original page. Usually the source of the error was evident, but once obvious errors were corrected some calculated means remained different to the published values. Where the error was limited to the last significant digit, the problem was assumed to be rounding errors and the calculated mean used. Occasionally the error was greater than this, and where the hourly values appeared plausible in continuity checking within the diurnal cycle and valid within meteorological parameters, the error was assumed to be within the published mean and the calculated mean was substituted, rather than make possibly arbitrary changes within the published hourly dataset. Changes to the published values were made only as a last resort, and most often these were clearly justified by a typographical error in the printed report.

The quality of the crowdsourced data was extremely high - when using three volunteers per observation the correct value was obtained much more than 95% of the time. The most frequent cause of missing or mistyped data values within a column was when identical values occurred on consecutive rows, when the eye would presumably skip to the second value and continue from there. This was particularly marked with wind observations, many of which look very similar, particularly in the summer months. Errors made when transcribing temperature observations were less frequent than for pressure, perhaps because the range of values (in °F) were more familiar; pressure readings, in inches of mercury, being less familiar to a public audience had an error rate about twice that of temperature.

After correcting for mistyped or missing transcribed data, almost all remaining errors were due to typographical or arithmetical errors in the original pages, for example, a 9 was typeset as a 6. If these errors occurred in the significant digits then these were obvious, e.g. if the pressure appeared to drop from close to 29 to 26 and back to 29 inches/Hg within the space of two hours, it was clearly physically implausible. As a testament to the standards of the original published volumes, in approximately 182,500 Ben Nevis Observatory dry-bulb hourly temperatures (December 1883 to September 1904), 153 errors were identified, an error rate in the published pages of just 0.08%. Similarly, for Fort William pressure observations from August 1890 to September 1904, approximately 132,000 observations, 180 errors were identified, just 0.14%.

However, it is inevitable that there are additional errors made in the less significant digits which we will never discover but these will likely be within the observational uncertainties. It was also noted that the volunteers made less errors as the project progressed - they clearly became more aware of the likely ranges of the data being entered and more likely to pick up their own errors. They also discussed typographical errors they had spotted in the project discussion web pages.

# 3 Original observations and unit conversions

## 3.1 Equipment used

The Fort William Observatory was provided with standard automatic recording equipment by the Meteorological Office. This used continuous photographic recording of temperature and barometric pressure in a North Wall screen, with hourly values being extracted from the traces. Check readings were made several times a day to correct if necessary the scale of the traces. A self-recording Beckley raingauge was used to provide the hourly rainfall totals.

At the Ben Nevis Observatory, because of the severe icing which could occur during the greater part of the year, self-recording instruments could not be used and hourly manual observations were made by the observers. Pressure readings were obtained from a Fortin mercury barometer mounted in the Office. The charts from a Richard's aneroid barograph were used as a check. Dry and wet bulb thermometers were mounted in a standard Stevenson Screen during the summer months - the ground below the screen was broken rock with no vegetation. When snow was on the ground the thermometers were housed in screens on ladder-like stands so that the screens could be raised or lowered to keep the thermometers between 3 and 5 feet above the surface. Because of the icing, self-registering maximum and minimum thermometers were not used and if a screen became severely iced up it was taken inside to thaw out and a substitute screen and thermometers used. When the temperature was below $0^{o}$C great care was taken to make sure that, before the reading was made, the muslin on the wet bulb thermometer was coated with ice - becoming an ice bulb. During major storms, when it would have been unsafe to go out to the screen, temperature readings were obtained from thermometers mounted on the outside of the tower, whose scales could be read from inside the tower.

For the Ben Nevis observations, the daily minima and maxima dry bulb temperatures are the lowest and highest hourly observed values, whereas for Fort William they were recorded using separate screened minimum and maximum thermometers.

Two duplicate raingauges were used at the summit. They were of 5 inches diameter and had rounded bases so that they could be set with their top 1 foot above the surface and levelled. They were exchanged each hour, being brought inside for measurement of the rainfall or melting of snow. Hourly sunshine figures were obtained from the charts provided by a Campbell-Stokes sun recorder, which had an unobstructed horizon. Wind direction and force were noted by an observer standing on the roof of the Observatory using a Ben Nevis scale 0-12 (see below) and consistency between observers was checked. During the summer months comparisons were made between the force estimates and the hourly winds recorded by a Robinson Cup anemometer mounted on the tower. Cloud species and amount (on a scale of 1 to 10) were recorded and other phenomena (e.g thunderstorms, haloes, glories, St Elmo's Fire, aurora etc.) were noted.

### 3.2 Additional observations made at Fort William School

Between December 1883 and December 1890, before the Fort William Observatory was opened, regular weather observations were undertaken at Fort William School, including pressure (five times daily), dry and wet bulb temperature (both five times daily), minimum and maximum dry bulb temperature, daily rainfall, wind strength and direction (twice daily), and cloudiness (three times daily). These were published in Buchan (1890) and Buchan and Omond (1902) and have also been rescued. The published format of those observations was less amenable to website digitisation, so a separate effort from the volunteers was requested. A spreadsheet template was made available for the volunteers to download, type in a specific month of data, and send back to the science team for checking.

### 3.3 Conversion factors and locations

We have converted all the pressure observations from the values tabulated to 3 decimal places in units of inches/Hg to mb by multiplying by 33.8639. The rainfall, measured in inches to 3 decimal places, has been converted to mm by multiplying by 25.4. Temperatures have been converted from Fahrenheit, measured to 1 decimal place, to Celsius by subtracting 32.0 and dividing by 1.8. The daily rainfall amounts, minimum and maximum temperatures are given for the period from midnight to midnight. Equivalent estimates for other periods could be calculated from the hourly data.

The resulting pressure and temperature values have been rounded to 1 decimal place, and the rainfall to 2 decimal places. The pressure observations at both Ben Nevis and Fort William had already been corrected to a temperature of 32°F, and at Fort William had already been reduced to mean sea level. The altitude of the Fort William observatory was 42 feet or 13m. The Ben Nevis pressure observations are not corrected to mean sea level and were taken at 1345m above sea level. The Ben Nevis summit observatory location was at 56.80°N, 5.00°W, and the Fort William Observatory was at 56.81°N, 5.12°W.

The wind speed was recorded in 'Ben Nevis force', which was similar to the Beaufort scale, but with higher wind speeds for each category. These were recorded each hour as single force values, or a range, e.g. 2-3, or occasionally over several forces such as 2-4. We have used the mean force value for each hour, so a range of 2-3 is expressed as 2.5. Roy (2004) tabulates the conversion from force to knots, and Table 1 also shows m/s and mph. We fitted a fourth-order polynomial to these thresholds and this was used to derive wind speeds for all forces, including interpolating to non-integer values.

The calculation of relative humidity from the dry and wet bulb temperatures, pressure and wind force observations is described and analysed in Burt and Hawkins (2019). Several examples of near-zero relative humidity events at the summit are also described.

### 3.4 Data completeness and other data issues

The dataset produced has only a few gaps due to equipment failures when the original observations were made. A fraction of the values were published in square brackets indicating that they were estimates - these observations have been retained. One slightly odd feature of the data is the hourly rainfall at Fort William has a disproportionately large number of dry hours at 11am. No explanation has been found for this.

## 4 Digitised hourly weather observations

The digitised data for dry bulb temperature, rainfall and pressure for both Observatories are shown in Figures 3, 4 and 5 respectively. The observations made at Fort William School are shown in Figure 6.

For summit wind speed, we have produced a frequency histogram (Figure 7) to highlight the distribution of summit wind speeds, and the chance of exceeding a certain wind speed. Data exists for each hour on 4290 days. Ben Nevis Force 12 (in excess of 113 kn, 57 m/s) was only observed on one occasion - between 8am and 2pm on 2nd April 1901 - and 15 days experienced Force 11 or higher - roughly once per year on average.

The winds observed at the summit are much affected by the local topography. For example, where the pressure pattern would have indicated very strong westerlies or northwesterlies, the wind was deflected around the nearby peak of Carn Dearg and lighter than expected but very gusty northerlies were observed at the summit (Roy, 2004). This is likely to lead to an underestimation of the climatology relating to the strength of the wind on nearby summits.

### 4.1 Average and record values

For Ben Nevis summit, the mean annual average temperature between 1884-1903 was −0.3°C. The lowest hourly temperatures recorded were −17.4°C (dry bulb), −17.6°C (wet bulb) on Ben Nevis, and −11.4°C (dry bulb), −11.7°C (wet bulb) in Fort William. The highest hourly temperatures were 19.1°C (dry bulb), 14.4°C (wet bulb) on Ben Nevis, and 27.2°C (dry bulb), 20.8°C (wet bulb) in Fort William. The coldest day on the summit occurred on 7th February 1895 when the average temperature was −16.0°C.

The lowest pressure observed at the summit of Ben Nevis was 784.9mb on January 26th 1884, roughly equivalent to 929mb at sea level. The highest pressure was 889.2mb (or 1052mb at sea level) on 31st January 1902. On the same day, the Fort William observatory recorded 1053mb and Aberdeen recorded 1053.6mb - the highest pressure ever observed in the British Isles (Burt, 2007).

The most rainfall during a day at the summit observatory was 185mm on 3rd October 1890. On 10th December 1884, 33mm fell in a single hour. The corresponding records in Fort William were 79mm and 16mm respectively, on different days.

### 4.2 Case study: February 1903

In late February 1903 a severe storm hit the British Isles, causing considerable damage to trees and buildings (Shaw, 1903), including 3,000 trees blown down in Phoenix Park, Dublin. This event is now known as the 'Ulysses' storm as these impacts were mentioned in the novel of the same name by James Joyce, with the events being set in 1904, the year after the storm:

*Lady Dudley was walking home through the park to see all the trees that were blown down by that cyclone last year and thought she'd buy a view of Dublin.* (Joyce, 1922)

The rescued hourly observations for this event are shown in Figure 8, showing the detail now available. For example, the wind speed can be seen to increase just before the storm passes over Ben Nevis, before dropping rapidly.

Assimilating these newly rescued pressures into long centennial reanalyses (e.g. Compo et al. 2011) will improve the dynamical reconstruction of this event and many similar storms and interesting weather events.

## 5 Auroral observations

Many modern technological systems are prone to disruption or damage from space weather phenomena and cost-effective design of these systems requires us to have an accurate climatology of near-Earth space. The problem in constructing such a climatology is that we have direct measurements of near-Earth space from only the last 50 years which is inadequate to characterise the range of possible conditions, especially considering the dominant variation is the decadal-scale sunspot cycle, added to which are centennial-scale drifts.

To try to build a useful space climatology, historic ground-based observations such as telescopic observations of sunspots (from 1612 onwards), magnetometer observations of geomagnetic activity (from about 1845 onwards) and naked-eye observations of the aurora are used. Potentially, the auroral data stretch back over millennia, but there are major problems in interpreting them. As a consequence, auroral sightings have not been used as much.

Because of the offset of the geographic and geomagnetic poles, the geographic latitude of peak auroral occurrence varies with longitude, but the available hours of darkness and its seasonality depends on geographic latitude. Furthermore, the secular change in the geomagnetic field means that the consequent annual and diurnal variations in the probability of observing aurora depends not only on longitude but also on time. Added to the biases that this causes, there are other spatial and temporal factors such as the distribution of population, of cloud cover, of street lighting, and the willingness of a society to keep records of natural phenomena. All of these factors mean that global statistics on the occurrence of low-latitude aurora do not form a homogeneous metric.

One way to reduce these problems is to restrict the longitudes used to compile the statistics and for this reason Lockwood and Barnard (2015) compiled a catalogue of sightings from the UK. After 1900, we have an excellent record of aurorae in the UK, with data collected from observatories and the many (manned) lighthouses that were constructed around Scottish coasts in the late 19th century. As we extend the sequence before 1900, the record increasingly depends a few key regular observers and serendipitous observations reported in newspapers. But, in the late 19th century the Ben Nevis observatory was a prime location for detecting aurorae. Figure 9 is an overview of the Ben Nevis observations, of which 374 were recorded. The mauve histogram shows the number of nights per year on which aurora was observed at the observatory and the grey histogram the number of nights where such observations were not matched by an observation on the same night at a different location. This points to a general under-reporting of aurora at this time. The orange histogram shows the total number of nights on which aurora were seen in the UK. There were many nights on which aurora was seen elsewhere, but not at Ben Nevis, which also suggests that cloud cover there limited the number of auroral observations.

Data from observatories, or from experienced regular reporters of meteorological phenomena, have a major advantage over the opportunistic sightings, because it is known when it could not have been observed. The supporting information of cloud conditions at the observatory would be important in interpreting all the UK data as it will help us make a statistical allowance for the effect of cloud in studying the occurrence probability. However, these cloud observations have yet to be rescued.

## 6 Conclusions

Thousands of citizen scientists have successfully rescued millions of weather observations taken every hour at two nearby sites in the Scottish Highlands between 1883-1904. The use of volunteers allowed the digitisation of the data to be achieved more quickly and more cheaply than commerical digitisation.

This project built on the success of OldWeather.org (Freeman *et al.*, 2017) and has since been adopted in a new phase of WeatherRescue.org, and by other projects such as SouthernWeatherDiscovery.org.

These observations will be passed to the Met Office to be included in the official UK weather records, and to the Copernicus Climate Change Data Rescue Service to be added to the international databases. The Ben Nevis auroral observations also help fill in a gap in our auroral sightings records.

The data recorded so diligently over a century ago on top of a cold, wet, windy mountain are now available for anyone to analyse. The legacy of the dedicated observers will be a permanent record of the weather they experienced over a century ago.

# Acknowlegements

This project would not have been possible without the tireless efforts of the thousands of volunteers who donated their spare time to help rescue this unique dataset. We also relied on the Zooniverse, and their free-to-use Project Builder, which allowed us to create this project with limited time and financial resources. The UK Natural Environment Research Council (NERC) provided some seed funding through their Public Engagement programme and the National Centre for Atmospheric Science also supported the project. PB was funded by the Joint DECC and Defra Integrated Climate Programme, DECC/Defra (GA01101). The Online Books Page at the Library of the University of Pennsylvania provided access to scans of the published observations. This publication uses data generated via the Zooniverse.org platform, development of which is funded by generous support, including a Global Impact Award from Google, and by a grant from the Alfred P. Sloan Foundation.

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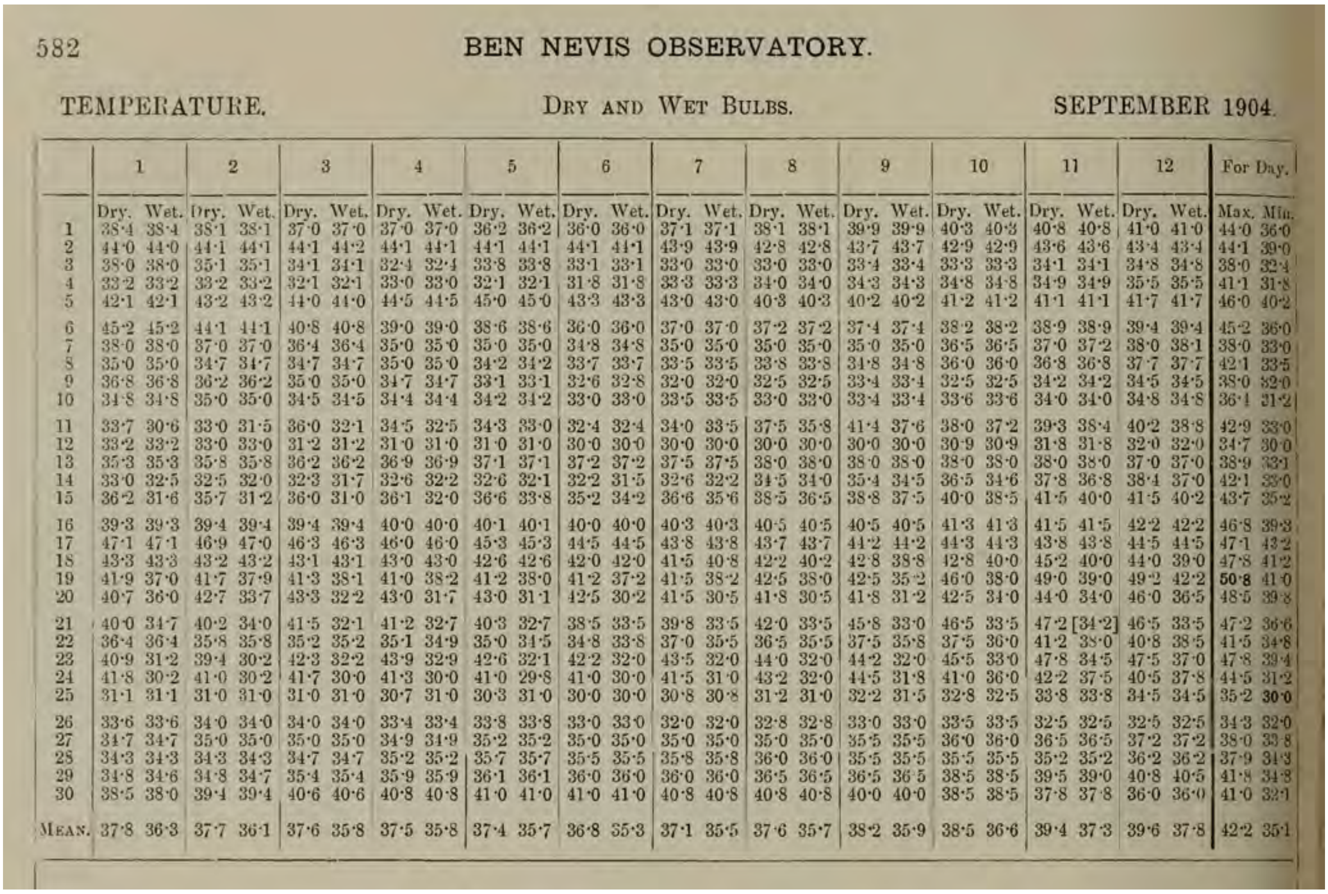
Figure 1: **Photographs taken on the summit of Ben Nevis by the Victorian-era meteorologists. Images from Royal Meteorological Society collection, held as part of the Met Office archive at National Records of Scotland.**

Table 1: **Conversion from tabulated wind forces to m/s and mph.**

| Ben Nevis Force | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Knots | 0 | 5 | 10 | 18 | 26 | 34 | 43 | 52 | 63 | 73 | 84 | 97 | 113 |
| m/s | 0 | 2.5 | 5.0 | 9.1 | 13.1 | 17.1 | 21.6 | 26.2 | 31.7 | 36.7 | 42.2 | 48.8 | 56.8 |
| mph | 0 | 5.6 | 11.3 | 20.3 | 29.3 | 38.3 | 48.4 | 58.5 | 70.9 | 82.1 | 94.5 | 109.1 | 127.1 |



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TEMPERATURE. DRY AND WET BULBS. SEPTEMBER 1904.

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. |
| 1 | 38·4 | 38·4 | 38·1 | 38·1 | 37·0 | 37·0 | 37·0 | 37·0 | 36·2 | 36·2 | 36·0 | 36·0 |
| 2 | 44·0 | 44·0 | 44·1 | 44·1 | 44·1 | 44·2 | 44·1 | 44·1 | 44·1 | 44·1 | 44·1 | 44·1 |
| 3 | 38·0 | 38·0 | 35·1 | 35·1 | 34·1 | 34·1 | 32·4 | 32·4 | 33·8 | 33·8 | 33·1 | 33·1 |
| 4 | 33·2 | 33·2 | 33·2 | 33·2 | 32·1 | 32·1 | 33·0 | 33·0 | 32·1 | 32·1 | 31·8 | 31·8 |
| 5 | 42·1 | 42·1 | 43·2 | 43·2 | 44·0 | 44·0 | 44·5 | 44·5 | 45·0 | 45·0 | 43·3 | 43·3 |
| 6 | 45·2 | 45·2 | 44·1 | 44·1 | 40·8 | 40·8 | 39·0 | 39·0 | 38·6 | 38·6 | 36·0 | 36·0 |
| 7 | 38·0 | 38·0 | 37·0 | 37·0 | 36·4 | 36·4 | 35·0 | 35·0 | 35·0 | 35·0 | 34·8 | 34·8 |
| 8 | 35·0 | 35·0 | 34·7 | 34·7 | 34·7 | 34·7 | 35·0 | 35·0 | 34·2 | 34·2 | 33·7 | 33·7 |
| 9 | 36·8 | 36·8 | 36·2 | 36·2 | 35·0 | 35·0 | 34·7 | 34·7 | 33·1 | 33·1 | 32·6 | 32·8 |
| 10 | 34·8 | 34·8 | 35·0 | 35·0 | 34·5 | 34·5 | 34·4 | 34·4 | 34·2 | 34·2 | 33·0 | 33·0 |
| 11 | 33·7 | 30·6 | 33·0 | 31·5 | 36·0 | 32·1 | 34·5 | 32·5 | 34·3 | 33·0 | 32·4 | 32·4 |
| 12 | 33·2 | 33·2 | 33·0 | 33·0 | 31·2 | 31·2 | 31·0 | 31·0 | 31·0 | 31·0 | 30·0 | 30·0 |
| 13 | 35·3 | 35·3 | 35·8 | 35·8 | 36·2 | 36·2 | 36·9 | 36·9 | 37·1 | 37·1 | 37·2 | 37·2 |
| 14 | 33·0 | 32·5 | 32·5 | 32·0 | 32·3 | 31·7 | 32·6 | 32·2 | 32·6 | 32·1 | 32·2 | 31·5 |
| 15 | 36·2 | 31·6 | 35·7 | 31·2 | 36·0 | 31·0 | 36·1 | 32·0 | 36·6 | 33·8 | 35·2 | 34·2 |
| 16 | 39·3 | 39·3 | 39·4 | 39·4 | 39·4 | 39·4 | 40·0 | 40·0 | 40·1 | 40·1 | 40·0 | 40·0 |
| 17 | 47·1 | 47·1 | 46·9 | 47·0 | 46·3 | 46·3 | 46·0 | 46·0 | 45·3 | 45·3 | 44·5 | 44·5 |
| 18 | 43·3 | 43·3 | 43·2 | 43·2 | 43·1 | 43·1 | 43·0 | 43·0 | 42·6 | 42·6 | 42·0 | 42·0 |
| 19 | 41·9 | 37·0 | 41·7 | 37·9 | 41·3 | 38·1 | 41·0 | 38·2 | 41·2 | 38·0 | 41·2 | 37·2 |
| 20 | 40·7 | 36·0 | 42·7 | 33·7 | 43·3 | 32·2 | 43·0 | 31·7 | 43·0 | 31·1 | 42·5 | 30·2 |
| 21 | 40·0 | 34·7 | 40·2 | 34·0 | 41·5 | 32·1 | 41·2 | 32·7 | 40·3 | 32·7 | 38·5 | 33·5 |
| 22 | 36·4 | 36·4 | 35·8 | 35·8 | 35·2 | 35·2 | 35·1 | 34·9 | 35·0 | 34·5 | 34·8 | 33·8 |
| 23 | 40·9 | 31·2 | 39·4 | 30·2 | 42·3 | 32·2 | 43·9 | 32·9 | 42·6 | 32·1 | 42·2 | 32·0 |
| 24 | 41·8 | 30·2 | 41·0 | 30·2 | 41·7 | 30·0 | 41·3 | 30·0 | 41·0 | 29·8 | 41·0 | 30·0 |
| 25 | 31·1 | 31·1 | 31·0 | 31·0 | 31·0 | 31·0 | 30·7 | 31·0 | 30·3 | 31·0 | 30·0 | 30·0 |
| 26 | 33·6 | 33·6 | 34·0 | 34·0 | 34·0 | 34·0 | 33·4 | 33·4 | 33·8 | 33·8 | 33·0 | 33·0 |
| 27 | 34·7 | 34·7 | 35·0 | 35·0 | 35·0 | 35·0 | 34·9 | 34·9 | 35·2 | 35·2 | 35·0 | 35·0 |
| 28 | 34·3 | 34·3 | 34·3 | 34·3 | 34·7 | 34·7 | 35·2 | 35·2 | 35·7 | 35·7 | 35·5 | 35·5 |
| 29 | 34·8 | 34·6 | 34·8 | 34·7 | 35·4 | 35·4 | 35·9 | 35·9 | 36·1 | 36·1 | 36·0 | 36·0 |
| 30 | 38·5 | 38·0 | 39·4 | 39·4 | 40·6 | 40·6 | 40·8 | 40·8 | 41·0 | 41·0 | 41·0 | 41·0 |
| MEAN. | 37·8 | 36·3 | 37·7 | 36·1 | 37·6 | 35·8 | 37·5 | 35·8 | 37·4 | 35·7 | 36·8 | 35·3 |

| | 7 | | 8 | | 9 | | 10 | | 11 | | 12 | | For Day. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Max. | Min. |
| 1 | 37·1 | 37·1 | 38·1 | 38·1 | 39·9 | 39·9 | 40·3 | 40·3 | 40·8 | 40·8 | 41·0 | 41·0 | 44·0 | 36·0 |
| 2 | 43·9 | 43·9 | 42·8 | 42·8 | 43·7 | 43·7 | 42·9 | 42·9 | 43·6 | 43·6 | 43·4 | 43·4 | 44·1 | 39·0 |
| 3 | 33·0 | 33·0 | 33·0 | 33·0 | 33·4 | 33·4 | 33·3 | 33·3 | 34·1 | 34·1 | 34·8 | 34·8 | 38·0 | 32·4 |
| 4 | 33·3 | 33·3 | 34·0 | 34·0 | 34·3 | 34·3 | 34·8 | 34·8 | 34·9 | 34·9 | 35·5 | 35·5 | 41·1 | 31·8 |
| 5 | 43·0 | 43·0 | 40·3 | 40·3 | 40·2 | 40·2 | 41·2 | 41·2 | 41·1 | 41·1 | 41·7 | 41·7 | 46·0 | 40·2 |
| 6 | 37·0 | 37·0 | 37·2 | 37·2 | 37·4 | 37·4 | 38·2 | 38·2 | 38·9 | 38·9 | 39·4 | 39·4 | 45·2 | 36·0 |
| 7 | 35·0 | 35·0 | 35·0 | 35·0 | 35·0 | 35·0 | 36·5 | 36·5 | 37·0 | 37·2 | 38·0 | 38·1 | 38·0 | 33·0 |
| 8 | 33·5 | 33·5 | 33·8 | 33·8 | 34·8 | 34·8 | 36·0 | 36·0 | 36·8 | 36·8 | 37·7 | 37·7 | 42·1 | 33·5 |
| 9 | 32·0 | 32·0 | 32·5 | 32·5 | 33·4 | 33·4 | 32·5 | 32·5 | 34·2 | 34·2 | 34·5 | 34·5 | 38·0 | 32·0 |
| 10 | 33·5 | 33·5 | 33·0 | 33·0 | 33·4 | 33·4 | 33·6 | 33·6 | 34·0 | 34·0 | 34·8 | 34·8 | 36·4 | 31·2 |
| 11 | 34·0 | 33·5 | 37·5 | 35·8 | 41·4 | 37·6 | 38·0 | 37·2 | 39·3 | 38·4 | 40·2 | 38·8 | 42·9 | 33·0 |
| 12 | 30·0 | 30·0 | 30·0 | 30·0 | 30·0 | 30·0 | 30·9 | 30·9 | 31·8 | 31·8 | 32·0 | 32·0 | 34·7 | 30·0 |
| 13 | 37·5 | 37·5 | 38·0 | 38·0 | 38·0 | 38·0 | 38·0 | 38·0 | 38·0 | 38·0 | 37·0 | 37·0 | 38·9 | 33·1 |
| 14 | 32·6 | 32·2 | 34·5 | 34·0 | 35·4 | 34·5 | 36·5 | 34·6 | 37·8 | 36·8 | 38·4 | 37·0 | 42·1 | 33·0 |
| 15 | 36·6 | 35·6 | 38·5 | 36·5 | 38·8 | 37·5 | 40·0 | 38·5 | 41·5 | 40·0 | 41·5 | 40·2 | 43·7 | 35·2 |
| 16 | 40·3 | 40·3 | 40·5 | 40·5 | 40·5 | 40·5 | 41·3 | 41·3 | 41·5 | 41·5 | 42·2 | 42·2 | 46·8 | 39·3 |
| 17 | 43·8 | 43·8 | 43·7 | 43·7 | 44·2 | 44·2 | 44·3 | 44·3 | 43·8 | 43·8 | 44·5 | 44·5 | 47·1 | 43·2 |
| 18 | 41·5 | 40·8 | 42·2 | 40·2 | 42·8 | 38·8 | 42·8 | 40·0 | 45·2 | 40·0 | 44·0 | 39·0 | 47·8 | 41·2 |
| 19 | 41·5 | 38·2 | 42·5 | 38·0 | 42·5 | 35·2 | 46·0 | 38·0 | 49·0 | 39·0 | 49·2 | 42·2 | **50·8** | 41·0 |
| 20 | 41·5 | 30·5 | 41·8 | 30·5 | 41·8 | 31·2 | 42·5 | 34·0 | 44·0 | 34·0 | 46·0 | 36·5 | 48·5 | 39·8 |
| 21 | 39·8 | 33·5 | 42·0 | 33·5 | 45·8 | 33·0 | 46·5 | 33·5 | 47·2 | [34·2] | 46·5 | 33·5 | 47·2 | 36·6 |
| 22 | 37·0 | 35·5 | 36·5 | 35·5 | 37·5 | 35·8 | 37·5 | 36·0 | 41·2 | 38·0 | 40·8 | 38·5 | 41·5 | 34·8 |
| 23 | 43·5 | 32·0 | 44·0 | 32·0 | 44·2 | 32·0 | 45·5 | 33·0 | 47·8 | 34·5 | 47·5 | 37·0 | 47·8 | 39·4 |
| 24 | 41·5 | 31·0 | 43·2 | 32·0 | 44·5 | 31·8 | 41·0 | 36·0 | 42·2 | 37·5 | 40·5 | 37·8 | 44·5 | 31·2 |
| 25 | 30·8 | 30·8 | 31·2 | 31·0 | 32·2 | 31·5 | 32·8 | 32·5 | 33·8 | 33·8 | 34·5 | 34·5 | 35·2 | **30·0** |
| 26 | 32·0 | 32·0 | 32·8 | 32·8 | 33·0 | 33·0 | 33·5 | 33·5 | 32·5 | 32·5 | 32·5 | 32·5 | 34·3 | 32·0 |
| 27 | 35·0 | 35·0 | 35·0 | 35·0 | 35·5 | 35·5 | 36·0 | 36·0 | 36·5 | 36·5 | 37·2 | 37·2 | 38·0 | 33·8 |
| 28 | 35·8 | 35·8 | 36·0 | 36·0 | 35·5 | 35·5 | 35·5 | 35·5 | 35·2 | 35·2 | 36·2 | 36·2 | 37·9 | 34·3 |
| 29 | 36·0 | 36·0 | 36·5 | 36·5 | 36·5 | 36·5 | 38·5 | 38·5 | 39·5 | 39·0 | 40·8 | 40·5 | 41·8 | 34·8 |
| 30 | 40·8 | 40·8 | 40·8 | 40·8 | 40·0 | 40·0 | 38·5 | 38·5 | 37·8 | 37·8 | 36·0 | 36·0 | 41·0 | 32·1 |
| MEAN. | 37·1 | 35·5 | 37·6 | 35·7 | 38·2 | 35·9 | 38·5 | 36·6 | 39·4 | 37·3 | 39·6 | 37·8 | 42·2 | 35·1 |

Figure 2: **Example page from the published volumes, showing temperature observations for the Ben Nevis Observatory for September 1904. The columns indicate the time of day, with sub-columns for the dry and wet bulb thermometer data. The rows are the day of the month, with a mean along the bottom row. The final two columns show the maximum and minimum hourly values for the dry bulb thermometer that day.**

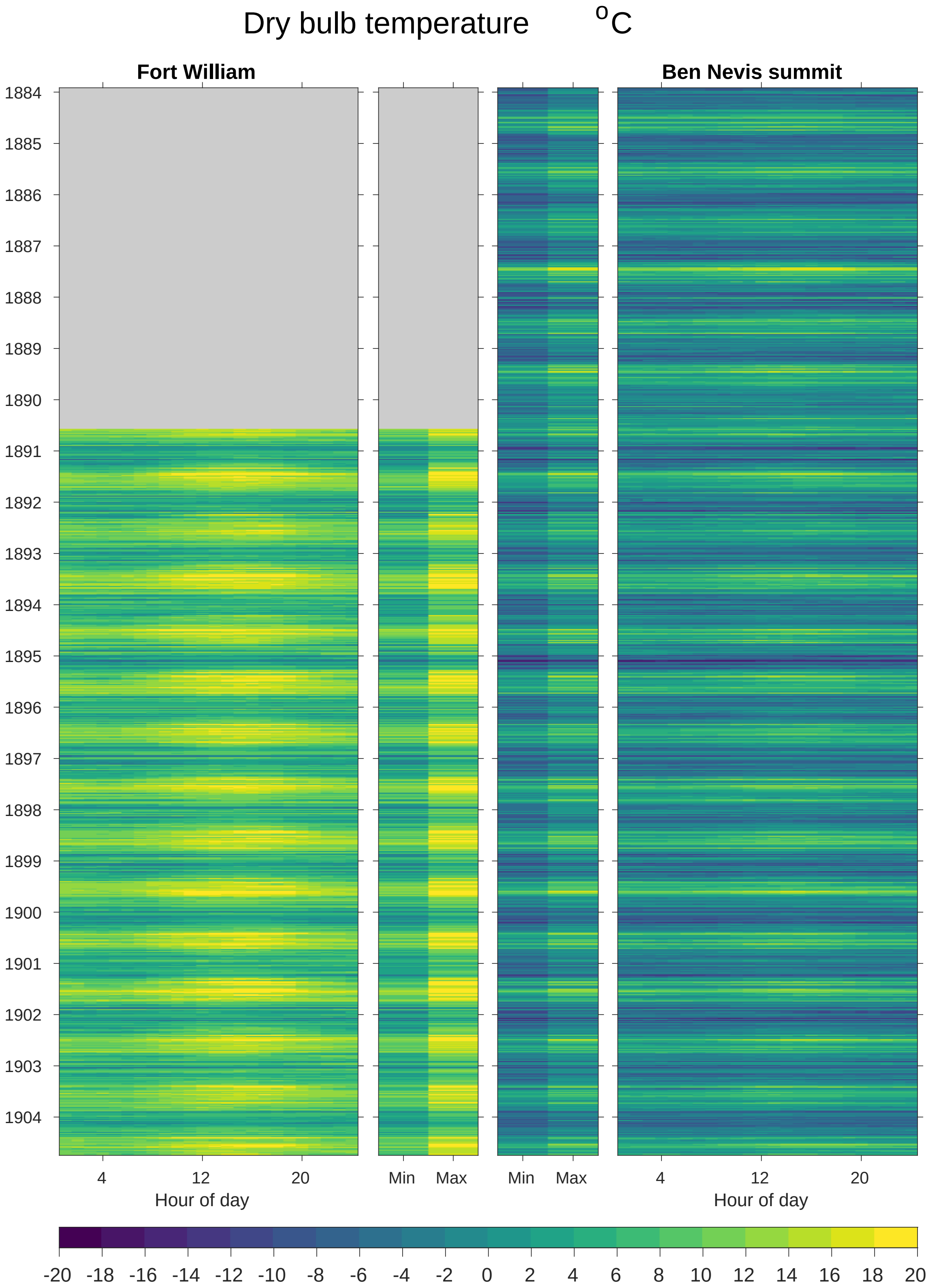


Figure 3: **Dry bulb temperature observations for Ben Nevis and Fort William, showing the hourly and daily extreme data. Grey regions indicate data not available.**

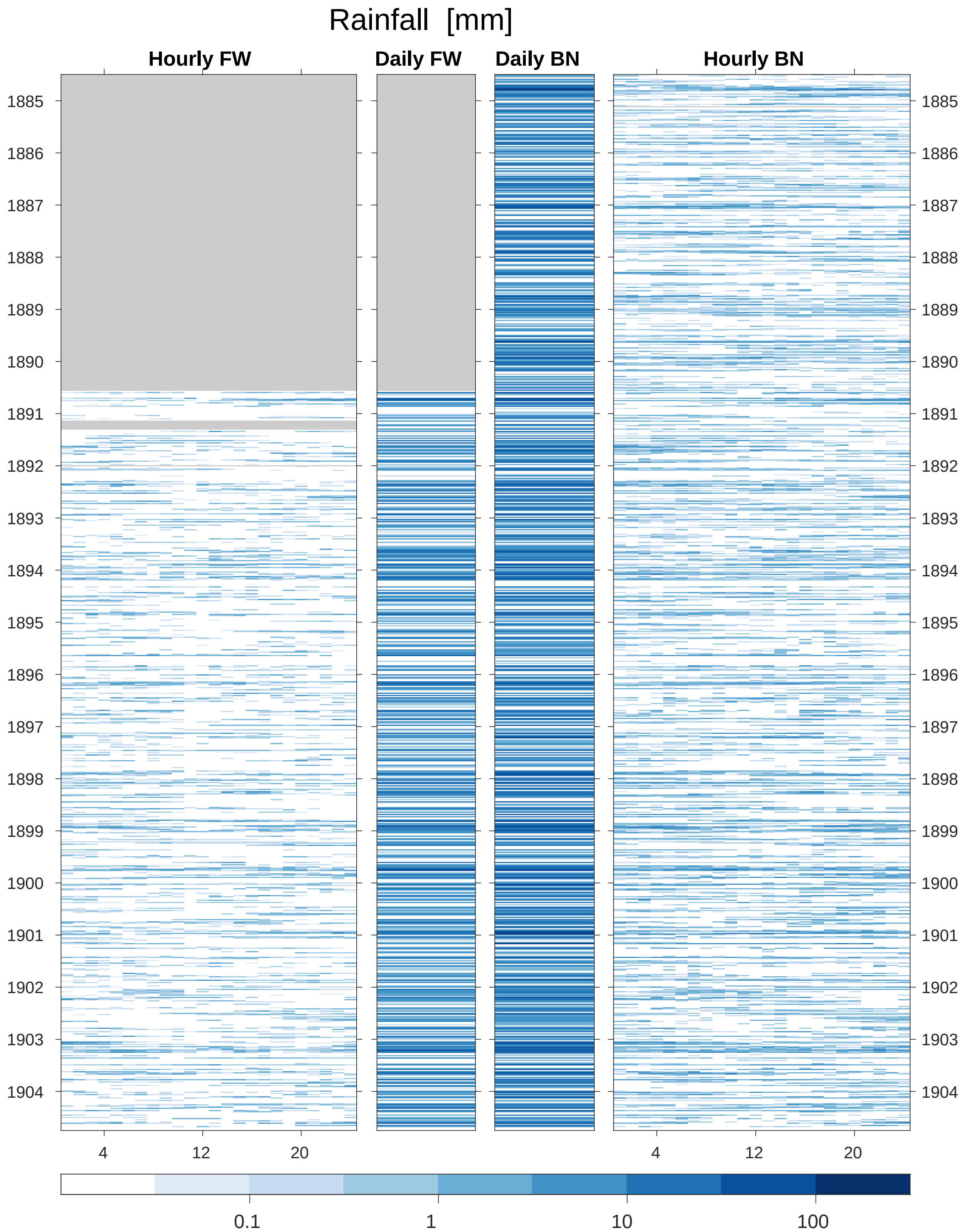


Figure 4: **Precipitation observations for Ben Nevis (BN) and Fort William (FW), showing the hourly and daily data. Grey regions indicate data not available.**

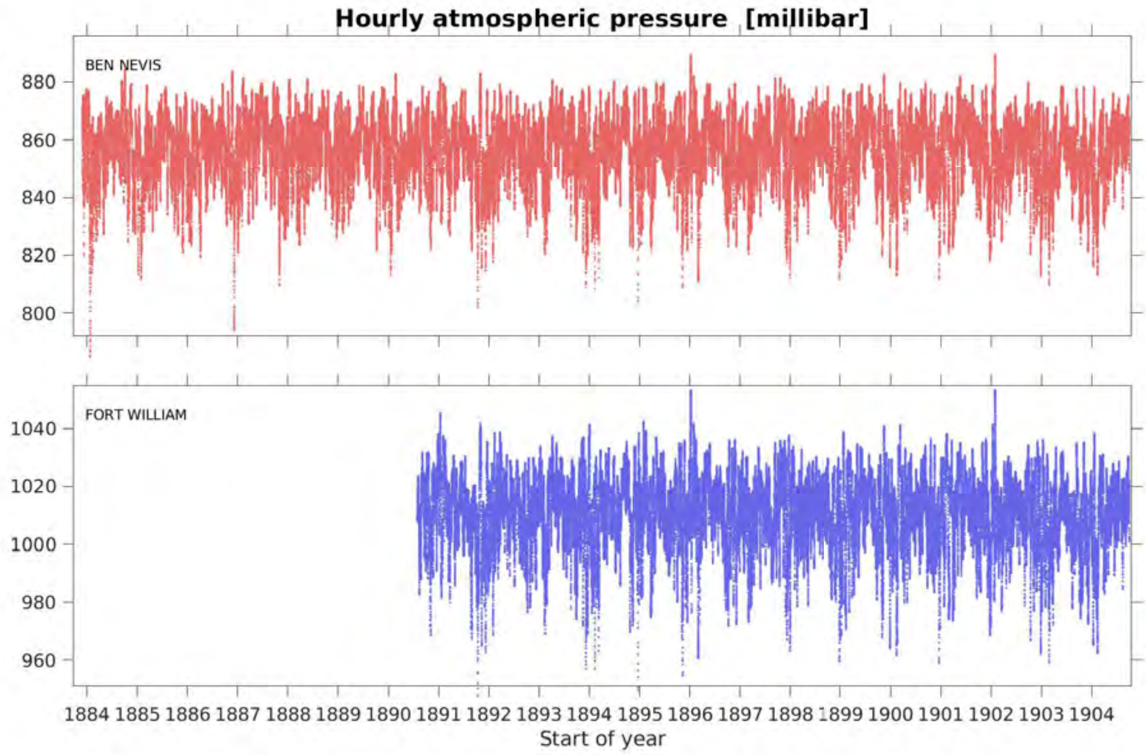


Figure 5: **Pressure observations for Ben Nevis and Fort William, showing the hourly data.**

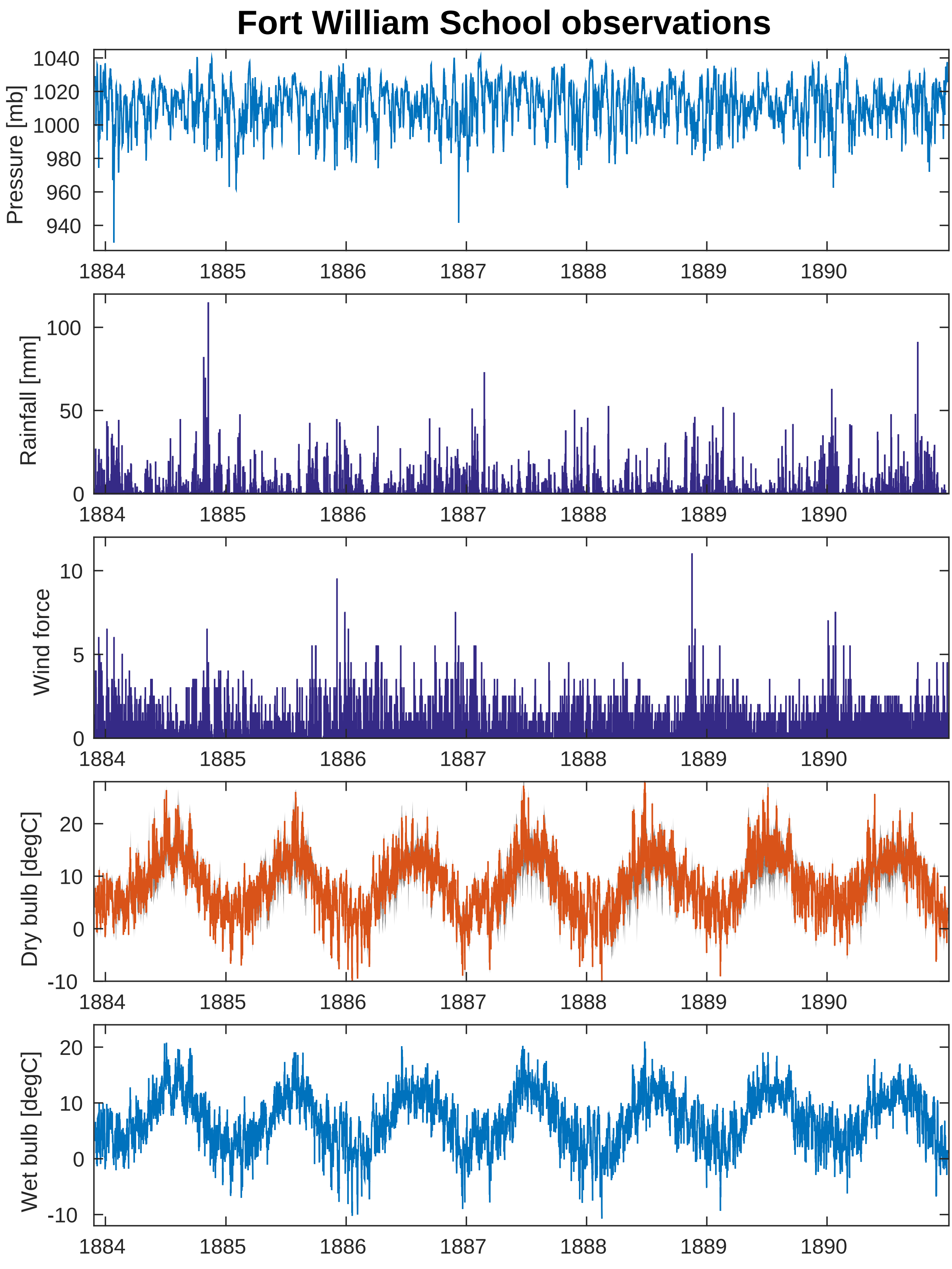


Figure 6: **The observations taken at Fort William School. These are five-times daily for temperature, pressure, and wind force, and daily for rainfall. Cloud amount (not shown) is also available. The grey shading for the dry bulb temperature indicates the daily minimum to maximum range.**

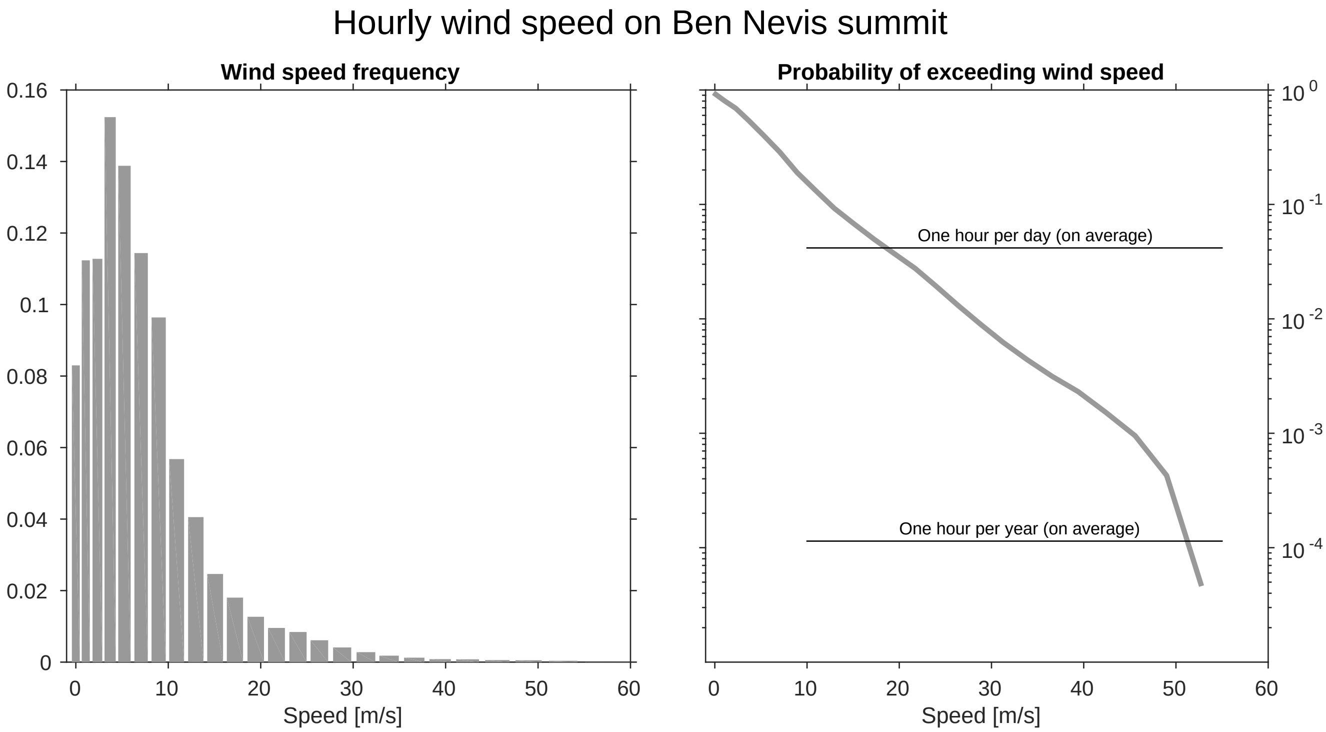


Figure 7: **Wind speed frequency for Ben Nevis summit using hourly observations, and the chance of exceeding a particular wind speed.**

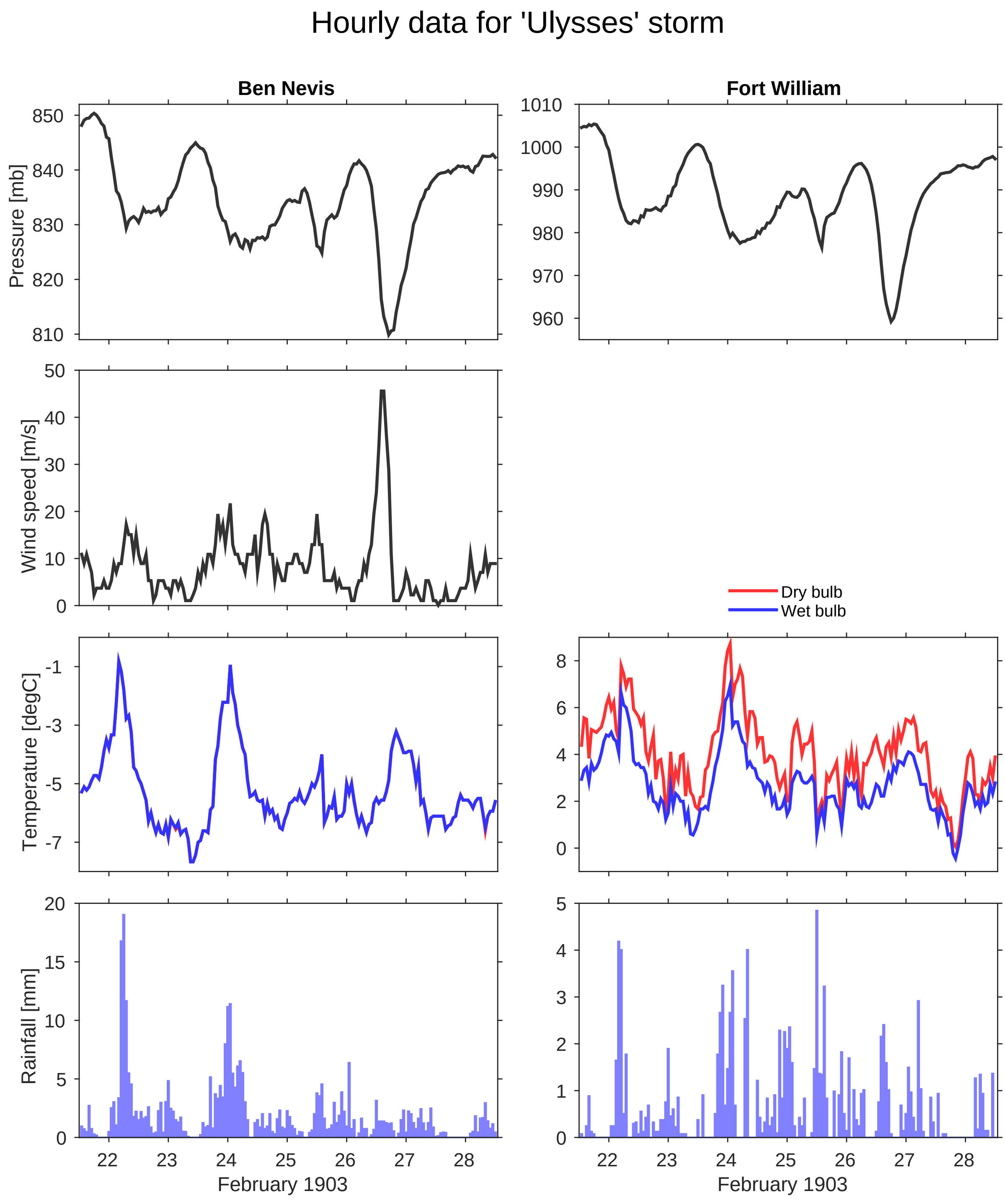


Figure 8: **A severe storm hit the UK in late February 1903, which is known as the *Ulysses* storm. The Ben Nevis and Fort William observations provide a valuable account for understanding this particular storm, and similar extreme events. For Ben Nevis, the observed wet and dry bulb temperatures are almost identical for the whole period shown, indicating very high humidity.**

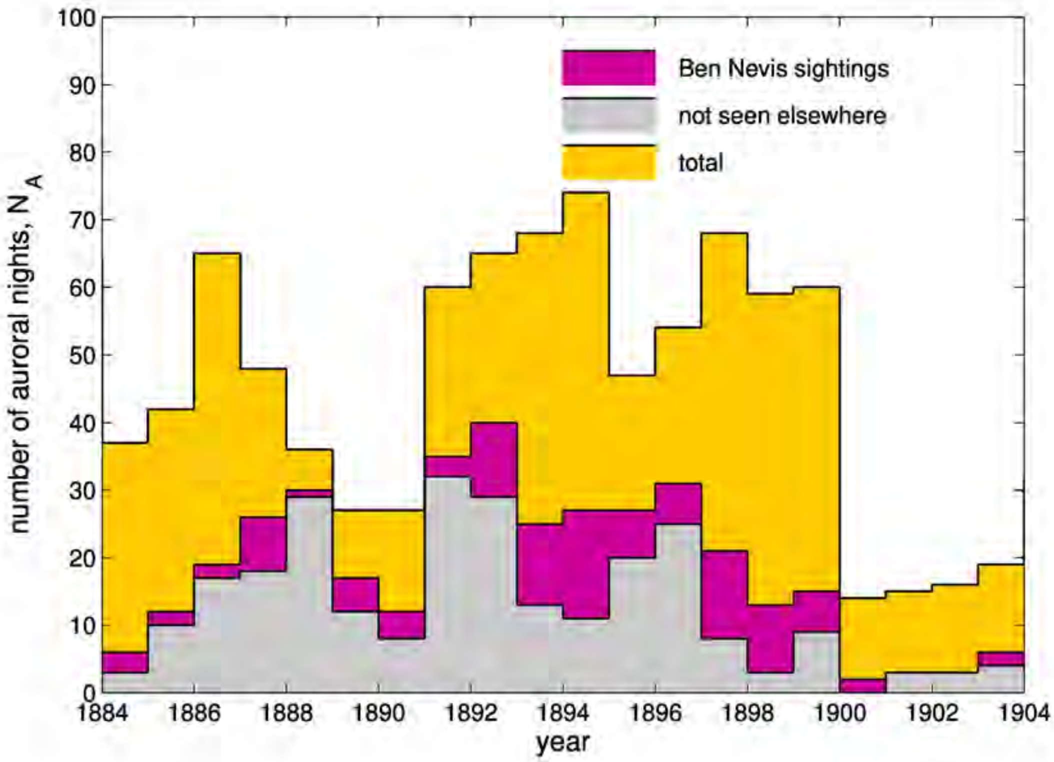


Figure 9: **Number of UK auroral sightings on Ben Nevis (purple), and those not seen elsewhere in the UK (grey). The total number from all sources is shown by the yellow histogram.**